FY 96 Report for the project "In-Situ Determination of Coating Material Acoustic Properties"

The objective of this project is to develop a method for in-situ determination of the acoustic quality and performance of mold-in-place coatings. The physical parameters which determine the acoustical performance of the coating are the complex longitudinal and shear moduli and the density. These properties will be determined in-situ by driving the coating with a broadband transient impulse and measuring the surface motion at several points with a laser Doppler probe.

Tasks completed in FY 96

The laser Doppler vibrometer (LDV) developed at Georgia Tech was used to measure both normal and tangential particle velocity components on the surface of compliant coatings driven normally with a shaker. The data was analized to determine the plane wave and the shear moduli of the coating. The following measurements were made.

Measurements on small coating samples

The first measurements [1] were made on coating samples provided by Walter Madigosky. These samples were 2 x 5 x 16 inches size, with 31% or 50% of air by volume. They were bonded with epoxy to a steel base plate, 1 x 24 x 24 inches size. Two driving pistons were used on the shaker - a large, 1.0 inch diameter, and a small, 0.2 inch diameter piston. The shaker was driven with a transient two cycle signal whose center frequency was varied over the range 3 - 15 kHz. The surface motion was measured at selected points at distances between 2 to 4 inches from the shaker.

The measured surface velocities were complicated by multiple reflections, of the waves generated by the shaker, from both the base plate *and* the sides of the sample. Therefore, in the data analysis it was necessary to use a very narrow time window to pick out only the initial part of the transient signal corresponding to direct propagation along the surface of the coating of waves from the shaker to the observation point. The results showed that the large diameter piston drive generated longitudinal (fast) waves, whilst the small diameter drive generated shear (slow) waves. The longitudinal and shear wave speeds were determined from the measured times of arrival of these waves. The values of the elastic moduli determined from the above LDV measurements are shown in Table 1, where they are compared with values determined using conventional methods on samples cut from the same coating. It can be seen that the two sets of values agree within 10%. These measurements show that the acoustical properties of the coating can be determined in-situ with the proposed LDV method.

However, the 10% accuracy achieved in the above measurements is not adequate for in-situ determination of acoustic performance. The objective in this project is to achieve a 2% accuracy in the determination of the complex sound speeds. One way to increase accuracy is to use a longer time window to record and analize a longer segment of the signal. However, the longer time window includes echoes from the boundaries. A large coating sample should be used to eliminate echoes from the sides. Also, a larger coating better simulates the conditions on the hull of a submarine. Therefore, the next measurements were made on a much larger coating sample.

Measurements on large coating samples

A larger coating sample, provided by Sam McKeon at CD, NSWC, was assembled. The material in this coating is different, much more compliant, than the material in the small coating samples. The coating sample was made much larger (2 x 30 x 30 inches). Measurements on this coating are made under conditions similar to the first measurements described above. A longer time window is used in the data analysis, to improve the accuracy of the wave time-of-flight measurements. This time window includes both the direct wave propagation from the shaker to the observation point and the first echo from the base plate. Because the measured signal is multipath, a more elaborate signal analysis is needed, as described in the next section.

An extensive set of measurements was completed on the large coating. A one cycle transient signal, with center frequency between 1 and 10 kHz, was used to drive the shakers. Both a magnetic and a piezoceramic drive shaker were used, and in each case measurements were made with both a large and a small drive piston attached to the shaker. The surface motion was measured at four points at distances between 2 and 4 inches from the shaker. This data is now being analized to determine the complex sound speeds.

Plans for FY 97

The data from the large coating samples will be analized to determine the phase velocity and the attenuation of longitudinal and shear waves in the coating. Several approaches will be used, described in order of increasing complexity, as follows: (1)A geometrical acoustics model, where the measured signal is the sum of a direct transient signal and an echo from the base plate. The time of flight and the attenuation of the two signals are adjustable parameters, and the base plate is assumed to be a rigid boundary. (2) Calculation of correlation functions between the drive and the measured signals, to separate the direct wave propagation from the echo from the base plate. (4) Use a model, based on integral transforms [2], for wave propagation in viscoelastic layers. The complex longitudinal and shear wave velocities in the coating will be adjusted to obtain the best fit between the model and the LDV data. (5) Use a finite element model for wave propagation in the coating. This approach is similar to the method developed at USRD, Orlando, for determining the complex elastic moduli of compliant material samples. (6) Other methods of signal analysis, such as cepstrum, and wavelet decomposition, may also be considered.

Measurements will be made on several large coating samples, with different air content and different matrix materials. These samples represent the spectrum of acceptable material parameters. We also desire to test several out-of-specification materials to determine the sensitivity of this method as a quality assurance check. [Consultation with both Walt Madigosky and the materials group at CDNSWC will be necessary]. In each case samples of the coating material will be cut from the coating and given to the materials group (Yves Berthelot) at Georgia Tech for independent measurement of the complex elastic moduli. This data will be compared with the values determined from in-situ LDV measurements. Based on the results of the above measurements and analysis, a design will be developed, at the end of FY 97, for an LDV system for in-situ monitoring of the acoustic quality of coatings on the hull of a submarine.

Presentations

1. Office of Naval Research Structural Dynamics and Structural Acoustics Program Review, February 12-15, 1996, Orlando, Florida.

References

1. Office of Naval Research Structural Dynamics and Structural Acoustics Program Review, February 12-15, 1996, Orlando, Florida.

2. R. L. Weaver, W. Sachse, and L. Niu, "Transient Ultrasonic Waves in a Viscoelastic Plate", J. Acoust. Soc. Am. **85**, 2255-2261 (1989).

Table 1

In-plane Measurements (Disk Drive)

Frequency	Measured wave speed (Optical probe) (m/s)	Measured wave speed (Standard technique) (m/s)
10 kHz	629	638
14 kHz	567	
18 kHz	610	

Out-of-plane Measurements (Point Drive)

Frequency	Measured wave speed (Optical probe) (m/s)	Measured wave speed (Standard technique) (m/s)
3 kHz	257	
5 kHz	214	224

Measurement error $\approx$ 10 %
(determined from the variation in wave speed measurements made at the same frequency).

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13. ABSTRACT (Maximum 200 words)

This report documents the progress on grant N00014-96-0175, In-Situ Determination of Acoustic Parameters of Navy Coatings for Mold In-Place Application. The objective of the project is to develop a method for in-situ determination of acousitc quality and performance of the mold in-place coatings. The physical paramenters which determine the acoustical performance are the complex loingitudinal and shear moduli and the density. These properties will be determined in-situ by driving the coating with a broadband transient impulse and measuring the surface motion at several points using a laser Doppler probe.

During the first year, the Laser Doppler Velocimetry measurement system was assembled and tested. Measurements taken on representative materials using the system and other conventional methods compared favorably. Investigation of several signal processing methods to resolve the multiple reflections was initiated. Future work will include application of these signal processing methods to more extensive coating samples as well as refinement of the measurement technique.

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